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Indicators of the Primary Impacts of Transportation Improvements

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Abstract: In this report, we present a review of the indicators of the primary impacts of transpo:tation improvements. The review was used to define the primary indicators necessary for the development of the overall transportation agency approach to the primary impact of transportation improvements.

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Executive Summary

This report was prepared by the Highway Innovations and Strategic Research Office, Research and Development Branch of the Ministry of Transportation. The report is a conpanion report to ECN-89-01 and is a summary of literature review on the subject of measures/indicators of transportation infrastructure effects on social and economic conditions of society. The main emphasis of the review was to identify sets of indicators which are deemed to be necessary and will provide a sufficient base for the assessment of decisions on transportation investment province wide. The report is distributed on a request basis.

1/ Travel Cost Impacts of Transportation Investments

1.1/ Introduction

Travel cost has long been used as a primary indicator for evaluating transportation investments. In the traditional approach, the analyst selects a travel cost component (such as travel time, vehicle operating costs or accident costs), identifies a pricing mechanism, quantifies savings and losses, and carries out a selected procedure for combining these into a travel cost calculation. The model used may be quite complex and comprehensive, including all costs that can be reasonably accounted for, or it may be simple and narrow, in some cases amounting to nothing more than a measurement of the number of travel minutes required for a set of defined trips over a specified section of roadway.

Whatever the nature of the model, travel cost indicators focus on direct user benefits, and sometimes in a rather limited way. In this chapter, the study, directed to the development of more broadly based indicators, is described. The indicators are intended to extend measured user benefits, such as travel time savings, into indicators that more fully reflect the concerns of those who make decisions about transportation investments. This requires the analysis to take account of a broader framework that includes the effects of transportation investment on cost savings that will accrue to consumers, business and government, on accessibility, on the environment, on economic development and possibly on other stated objectives of government.

The Ministry of Transportation (MTO) already maintains systems for user benefit analyses. It is anticipated that the data bases and analytic techniques used to operate them, and the results obtained from them will feed into some of the broader indicators proposed in the present program. At the same time, it is bound to be the case that the new indicators will require some information about travel facilities and impacts that is not now generated, or that is not now produced in a form directly usable in the new systems. Furthermore, the existing procedures for assessing user costs and benefits, while they have served well for many years, likely could be enhanced in various ways. These are the range of problems to which this study is directed.

The following steps will be involved in developing such an indicator assessment process:

1) a full description of user benefit data and analytical techniques now available and used in the Ministry;
2) the identification of the applicability of these to the broad indicators and revised techniques that will be developed in the present research program;

3) the development of plans and priorities to fill the gaps so identified;
4) the commencement of work on the implementation of certain enhancements to the present user benefit techniques that are already deemed desirable in their own right, and that do not depend on the adoption of the broad indicators involved in other proposals in this research program.

Within the general context described above, travel cost analysis usually proceeds with some or all of the following steps:

1) defining travel cost for a given transportation investment situation;
2) developing measurement or prediction techniques used for quantifying the selected cost components;
3) identifying acceptable and flexible procedures for pricing the travel cost components;
4) establishing the most appropriate procedure for using the above information to calculate travel costs for a specified transportation situation.

With minor qualification, pricing and assessment procedures are relatively well defined and accepted and do not require much elaboration here. The remainder of this discussion will therefore focus primarily on items 1 and 2 – defining travel costs and developing techniques for quantifying those costs.

1.2/ Identifying Cost Components

The principal components of user travel cost are usually identified as time costs, accident costs and vehicle operating costs (maintenance, fuel, consumption, tire wear, etc.). These costs are primarily dependent upon the traffic operating conditions encountered on a roadway segment, as imposed by a particular roadway situation. As depicted in Figure 1, a roadway situation can be uniquely defined by specifying the demand, geometric configuration, control and environmental characteristics.

Given such specification, the "actual" operating conditions can be established if one knows the typical operational characteristics of the roadway. Those characteristics are defined by speed-flow-capacity relationships (or the equivalent for interrupted flow facilities), historical trends in accident experience and vehicle operating costs. The time, accident and operating costs can then be determined directly from the resulting traffic operating conditions, provided that each cost component has been priced.

The idealized process depicted in Figure 1 is deceiving in its simplicity. Applying the procedure for an extended roadway section can become very complex due to the wide variety of roadway situations which may arise along its length due to the varying demand, geometric and environmental conditions encountered. These complexities are further compounded by such factors as behavioural and temporal variations. For simplicity these problems are largely ignored in the following discussions.

1.3/ Measuring/Predicting Travel Time

Quantifying travel time and delay for a given situation is usually accomplished either by direct measurement (test runs), by applying known speed-flow relationships, or some comvination of the two. In the case of using flow relationships, the complexities referred to above have been overcome to a large extent simply because vast amounts of data have been collected and analyzed over many years. However, large gaps still exist for some conditions, such as operation on two-lane roadways and variations imposed by weather conditions.

In addition, relatively little work has been done on comparing aggregations of travel time predicted using flow relaionships with directly measured travel time over extended roadway sections. It is clear that such aggregations will have to be used in this study. To measure travel times over all possible roadway situations would simply be too costly.

Another potential difficulty arises from our ability to identify current or future traffic demand on a roadway facility. In relative terms (i.e., before and after a transportation improvement), demand quantification is important both to establish unit travel costs and to accumulate those costs. Knowledge of 'actual' demand becomes especially important when traffic flows either are near or are expected to exceed capacity of the roadway sections. Under these conditions, the rate of cost accrual is very sensitive to minor demand fluctuation.

In summary, the main issues involved in estimating travel time are identifying demand patterns and representative speed-flow-capacity relationships for a selected set of roadway situations.

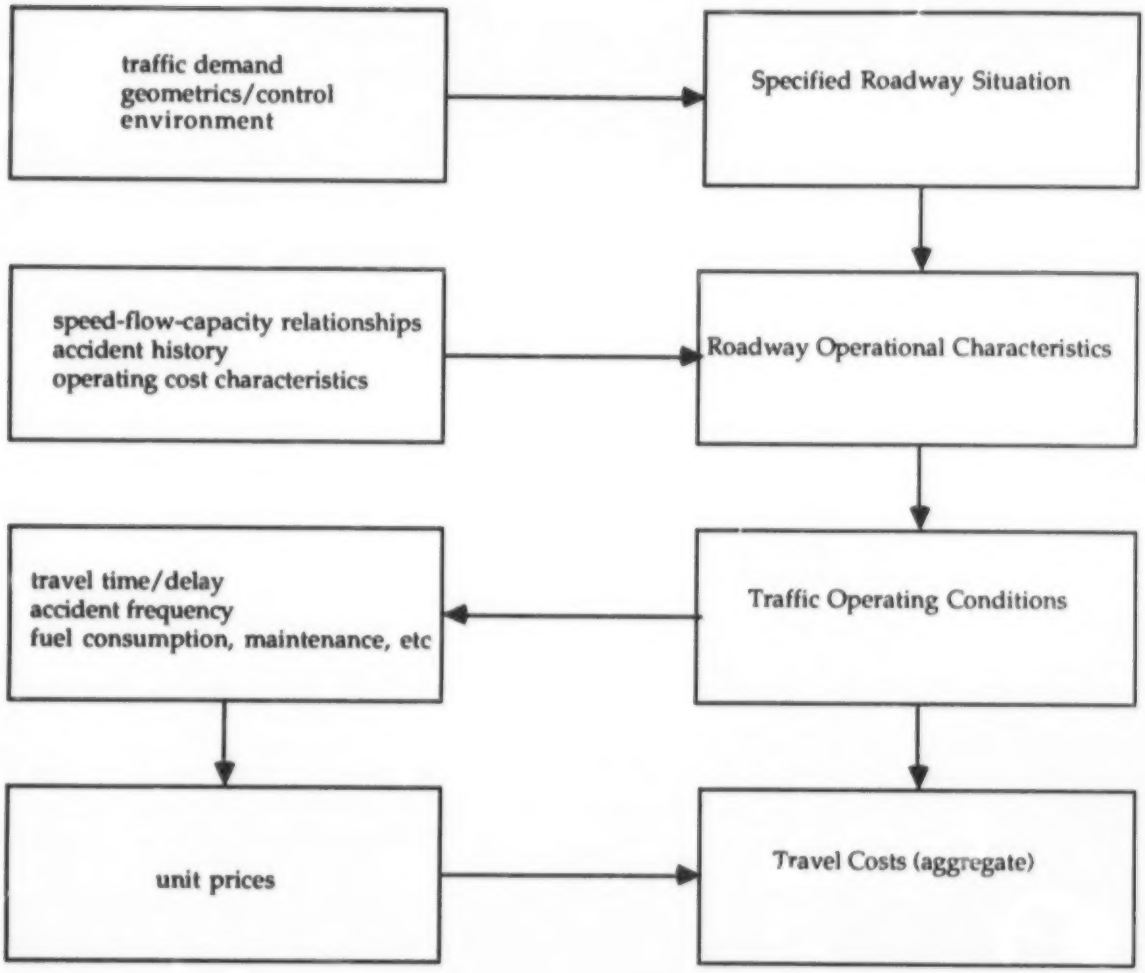

Figure 1/ Determining travel costs

The challenge in updating prediction methods for travel time and delay lies principally in two areas:

1) ensuring that methods can be reliably used to calculate travel time for a determined range of roadway types and conditions;
2) establishing a continuing 'calibration' procedure to systematically narrow the confidence limits for both relative and absolute estimates.

Responding to these general challenges will involve the following specific tasks:

1) specification of all possible roadway types to be used in future analysis efforts;
2) identification of all physical, operational, control, and environmental conditions expected for that set of roadways;
3) adoption or modification of existing speed-flow-capacity relationships (or equivalent) for the roadways and conditions identified;

and when such do not exist

4) development of new relationships and methods for travel time predictions. (e.g. two-lane roads and signalized arterials);
5) review of mechanisms for pricing travel time and updating unit prices as necessary.

Output from these broadly defined tasks would be demand-based travel time and delay relationships which reflect the current reality of traffic operation on Ontario roadway facilities. To a great extent, it will be possible to use current relationships, although some collection of new data will be necessary.

However, that luxury is not likely to extend to the calibration task. As suggested earlier, very little recent work has been done to compare actual travel time over a significant length of roadway (under a set of varying conditions) with travel times extrapolated from a 'point' estimate of speed. In this case, a carefully designed data collection effort will be required to yield an appropriate sample. Test runs in the field are mandatory for this, but need not be particularly extensive or costly if care is taken to choose representative locations.

1.4/ Measuring/Predicting Accidents

Due to the random nature of accident occurence, the safety impacts of a transportation improvement simply cannot be determined with the same level of confidence as other roadway operational characteristics. Basically the only reasonable method available is to estimate future accident

frequencies from known trends in accident rates for a specified roadway situation. Consequently, there are really only two issues of concern:

1) the existence of an accident history from which representative accident rates can be confidently established;
2) the adoption and application of a sound analytical technique for predicting future accident frequencies.

In the first instance, roadway operating agencies in Ontario have maintained relatively good accident data bases for many years; the Ministry in particular has a very comprehensice recording, updating and retrieval procedure in place. Consequently, aside from potential problems in the accuracy and coverage of accident records, we can reasonably assume that sufficient information exists to define historical trends. Some updating may be required to ensure an adequate statistical base across the range of roadway situations selected for analysis.

Regarding the second issue, recent advances in accident prediction methodology make it possible to apply improved analytical techniques. In particular, the relatively new Bayesian approach eliminates the regression-to-mean difficulties which were inherent in traditional accident prediction techniques using conventional methods (Hauer, 1986). The procedures are well documented and can be readily applied. The work in this area will be simply to implement the newer methodology and to prepare suitable accident data to go with it.

The process required to carry out this aspect of the user benefit study would include three basic components:

1) retrieval of accident data from existing files and preparation of trend statistics for all the roadway situations identified;
2) adoption and adaptation as necessary, of recently developed accident prediction techniques;
3) development of efficient procedures for regular updating and maintenance of the prediction processes (including determination of the unit cost of a specified accident type).

Output from these three basic tasks would provide the Ministry with readily usable techniques which could be confidently applied across a wide range of impact assessment efforts. Interestingly, the techniques thus developed could easily be used in an overall travel cost assessment package combining all cost components.

1.5/ Measuring/Predicting Operating Costs

Detailed information on the costs incurred for operating fleets of vehicles is available from corporations and government agencies. Records include precise accounting of operating expenditures for all types of maintenance (power trains, running gear, body, etc.), fuel, lubricants, and ancillary purchases such as insurance. Despite this, almost nothing is known of the nature of the overall relationship between the roadway situation and the accrual of such costs.

Attempts have been made to relate situation variables, such as road surface conditon and roadway alignment, to operating cost using standard regression techniques. To our knowledge, none of the efforts to date have been particularly successful. As the result of a flurry of Transportation Systems Management (TSM) work during the energy crisis in the mid-1970's, some data exist describing fuel consumption as a function of speed, stops and delay. Unfortunately, most of this type of data is very limited in applicability and can only be used for very clearly defined road segments and for older vehicle fleets.

There is need to develop a model of the relationship between aggregate operating conditions on a given roadway and aggregate vehicle operating cost. Although such a task appears daunting, order-of-magnitude estimates should be relatively easily obtained by accessing a combination of industry records and government census data.

It should be possible, for example, to identify the nature of costs encountered by a fleet operator on a particular roadway type. By carefully selecting appropriate carriers (and therefore roadway sites used by that fleet), it should be possible to obtain data for a reasonably representative range of roadway situations.

As part of this data collection process, information on the impact of transportation reliability should also be obtained. For example, does the (un)certainty of travel time over congested roadways induce business decisions regarding route selection, fleet size, and mode choice for goods delivery and if so, how do these factors affects productivity or profitability? Similar questions arise in relation to government-supported social programs such as transportation services for the elderly and disabled. Importantly, such information can be supplemented with data already in the public domain. For example, provincial and national input-output data can be accessed to determine transportation costs for specified industries. With appropriate manipulation, this would permit an estimate of the order-of-magnitude of benefits accruing to business from an investment in transportation.

The general tasks required to develop a method of relating vehicle operating cost to industrial productivity would include:

1) survey and identification of representative firms operating vehicles primarily within a specified roadway situation;
2) collection of vehicle operating cost data from those representative firms when possible;
3) development of an operating cost model for varying road situations using that data;
4) identification of relationships between vehicle operating cost and business productivity measures;
5) development of an overall business productivity indicator related to vehicle operating cost.

(The tasks in 4 and 5 above are discussed in more detail in Chapter Three).

Development of a representative data base and the methodology for analysis of 'true' vehicle operating costs is viewed as an important component of an overall framework for establishing indicators with which one can evaluate and communicate impacts.

1.6/ Research Effort Estimates

The following estimates have been provided on a purely speculative basis since the actual extent of data collection and methodology development will remain unknown for some indicators until the range of conditons over which information is desired is determined. The effort would obviously vary, dependent upon the scope of the work. In addition, the combination of interrelated projects would clearly result in savings.

1.6.1/ Travel Time Costs

It is estimated that a travel time study could be successfully mounted in a phased effort and require approximately 3-5 man-months per year. The first phase would include about equal emphasis on data collection, analysis and methodology updates. In subsequent phases, increasing attention would be given to developing a formal updating procedure with minor data collection in specified areas. Due to a relatively advanced state of experience and application in this area, it is likely that the vast majority of priority work could be accomplished in one fiscal year.

1.6.2/ Accident Costs

Based on the proposed direction of work related to estimating accident costs described earlier, the study team feels that a 2–3 man-month effort would be sufficient for an updating and

implementation phase. That estimate is based on the assumption that the Ministry will make available unit accident costs. An additional 3–5 man-month effort might be required to obtain and prepare adequate municipal road collision data, if that was deemed necessary.

1.6.3/ Vehicle Operating Costs

The study to determine vehicle operating costs for a set of selected roadway situations, and to establish the relationship between those costs and business productivity would be best conducted as a phased effort. The first phase would include extracting a sample of cost information from a few selected carriers, obtaining the necessary transport costs from input-output tables and developing preliminary relationships for business productivity. It is estimated that an acceptable exploratory effort would result from approximately a 3–5 man-month investment. Refinement of the data base and methods developed would take place in subsequent phases as determined from first phase results. It is possible of course, to scale the effort in either direction to define objectives and details.

Reference

[1] Hauer, Ezra, "On the Estimation of the Expected Number of Accidents"; Accident Analysis and Prevention, Vol. 18, No. 1; 1986.

2/ The Effects of Transportation Investments on Accessibility

2.1/ Introduction

Accessibility refers to the opportunities available to a defined population to participate in a defined set of activities. If a person must travel to the location of the activity chosen, the transportation system is a constraint on accessibility. Thus one possible measure of the effect of investment on a transportation facility is its impact on accessibility.

To define an accessibility index it is necessary to define the population involved, the travel facilities used, the activities to be considered and a model to link them together. Since a number of relevant activities exist, the problem is multi-dimensional. Examples of activities are: employment (measured by the number of jobs in a given zone), shopping (represented by some measure of retailing, such as the number of shops or the total floor area of shopping establishments) and health care (the number of hospital beds, physician offices, etc.). Many different types of indices are used.

To illustrate a somewhat complex accessibility index, consider the population-weighted Hansen index:

$$A_i = P_i \Sigma B_j f(c_{ij})$$

where A_i is the accessibility of zone i to the defined opportunities in all zones j, P_i is the population of zone i, B_j is the number of opportunities to do the specified activity in zone j, c_{ij} is the cost of travel from i to j, and f is a function that transforms travel cost into its deterrent effect on travel. Thus a zone's accessibility is defined as the number of opportunities to do some activity weighted (or "discounted") by the difficulty of reaching that zone.

A transportation investment, such as a new highway link, would reduce the cost of travel, c_{ij}, and could also induce an increase in the number of opportunities to participate in the specified activity, B_j. The resulting change in A_i is the incremental impact of the transportation investment on accessibility. Note that this formulation highlights possible links with other proposals in the present research program. For instance, the project on developmental impacts could be used to turn B_j into a function dependent on other variables.

The above measure refers to "integral accessibility", accounting for the access of zone i to the specified opportunities in all other zones. An index one step simpler is a measure of relative accessibility -- the

summation sign is removed and the index measures the accessibility of activities in a single zone j to the people in a single zone i. A still simpler version is to draw travel time contours around a zone containing the population of interest and then count the numbers of opportunities for each type of activity studied within each contour. An alternative approach to this version is to define a set of activities as the geographical starting point and then draw population contours, instead of activity contours. This is similar to a "trip generation" model of the sort used in transportation planning, though it is also referred to as an accessibility analysis. An illustration of its use is found in the planning studies prepared for the upgrading of the roadway network connecting roads south of the Niagara Escarpment to roadways north of the Escarpment in Hamilton and Stoney Creek. Two types of accessibility indicators were calculated for alternative routes: contour maps showing population within 10-, 15- and 20-minute travel times from selected activity centres, with and without the proposed investment, and an index measuring employment opportunities. The latter was calculated for a series of employment centres using data from the population contour maps to construct an index in which the population count within the 20-minute contour is weighted by the proportion of employment opportunities in the centre that defines the contour.

Turning again to more complex indices, the Hansen index can be "normalized" by dividing the above measure by ΣB_j; i.e., the opportunities in zone j are treated as a proportion of total opportunities in all zones. Another development of the idea would be to allow for more than one type of activity (e.g., employment and shopping) within a single index. This version was not encountered in the literature surveyed for this project, but, so long as one is willing to accept some sort of weighting scheme, in principle it can be done.

2.2/ Indicator Construction & Data Requirements

The ingredients needed for the construction of an accessibility indicator depend upon which form of the index is chosen. For a population-weighted version of the Hansen index it is necessary to have a zonal breakdown of the system to be studied, population by zone, a count of the opportunities for the activity or activities specified and a model for assigning travel time or cost between zones.

Because most of the data required are already collected, or would be generated by other projects in the present program, the marginal cost of calculating accessibility indices need not be high. For instance, in the context of a planning procedure in an urban centre in Ontario, in which a transportation authority has been instructed to deal with a specific need (e.g., reducing congestion on existing roads

by building new roads), much of the data needed to construct an accessibility measure are likely to be available already. A zonal structure for planning purposes will already have been defined and some sort of traffic model, that can be used to calculate travel times between zones, is likely to be in use. In the Hamilton-Wentworth study travel times were calculated with a traffic model already in use in the region. The model also contained population and employment data by zone. These data were forecasts for the year 2001. (Whether current data or projections are used depends on the purpose for which the index will be used.) Since that time the use of such models in southern Ontario city-regions has progressed further; similar models are calibrated in several centres, suggesting the possibility for some standardization across centres dealt with by MTO's Municipal Roads division.

Where such data are not already contained in computer models, obtaining them would be easy in some cases, more difficult in others. For example, population data are easily available from census publications. Employment data by place-of-work are also available for Subdivisions of Census Metropolitan Areas and for smaller centres. These data would be detailed enough for some purposes, but not for others. Similarly data on the location of shopping establishments can be more difficult to obtain on a systematic basis. Costs may have to be incurred for putting together data from planning records, standardizing available data and, in some cases, for special surveys. In most situations data required for the most commonly-used accessibility indices (e.g., those based on employment opportunities or shopping) are likely to be obtainable at reasonable cost from records at the regional or municipal level.

Marginal development costs of accessibility indicators may also be reduced by interaction between projects in the present research effort. The most directly relevant is the project to improve and develop travel cost indicators; it would provide direct inputs into accessibility calculations.

2.3/ Applicability

Accessibility measures are frequently used in transportation and land use planning at the local level. Urban planners might wish to compare a series of possible actions, such as the status quo and a number of alternative transportation facilities connecting two points that differ according to route and/or mode. A comparison of accessibility measures across alternatives could be useful in ranking projects. The focus of such a study can vary according to the activities considered. For example, it might have a business development focus, in which the attractiveness of retail shopping areas or employment centres is to be enhanced. Alternatively, it might feed into a program of rationalization

of government services, in which facilities such as hospitals, airports or educational facilities are to be made more accessible.

While accessibility indicators have been used more extensively in a local planning context, their use might be expanded to deal with planning in a regional context. An example would be the problem of choosing routes between northern Ontario and southern population centres that are to be further developed.

Accessibility indicators also provide a useful framework in which to make judgements about whether a community or a particular category of users are receiving an adequate level of service. In an economy that offers a high average level of service, the question of where funds should be applied can be difficult to answer. One approach would be to assert that the provision of an adequate level of accessibility for all citizens is an important goal for the transportation system. Implementation of a program to achieve such a goal would then involve a cross-community comparison of appropriate accessibility indices. For instance, accessibility of the handicapped to services could be compared in municipalities or other regional entities across Ontario.

One strength of an accessibility approach to this question is its breadth. Where a community lacks accessibility to a given type of activity the remedy may be in providing improved transportation or it may be in a reorganization of the activity itself. Thus accessibility analysis would be useful for MTO if it seeks to interact more in a cross-Ministry planning process. An example would be a joint Transportation-Health approach to the provision of medical and hospital services, where access to hospital services for a given community could be improved by investment in transportation (such as the building of a rural community airport) or by building a new hospital. Such considerations would appear to be especially applicable to the planning of government services in northern Ontario. To summarize, the Ministry should consider the use of accessibility analysis in various ways.

- It might be used in its traditional role, as a tool in the detailed planning of transportation facilities; for example, in its Municipal Roads division where provincial programs already involve interaction with urban planners who use accessibility analysis; or in its own planning of routes for new highways, commuter trains, etc. An illustration of the latter possibility is in relation to the expansion of the Province's major north-south traffic corridor.
- It might be used as a tool directed towards meeting provincial objectives regarding the distribution of transportation services across communities.

- It might play a role in developing a framework for cross-Ministry planning procedures.

In any of these roles accessibility indicators can be used in either a narrow context, in which the decision relates to one or more specific activities and in which the accessibility model used may be relatively simple, or a broad context, in which a more complicated accessibility index is used as a summary measure.

2.4/ Proposal for Action

Accessibility has not so far been focused upon as a way of summarizing Ministry objectives and the concept did not appear as a central concern in the interviews conducted by this study team in its attempt to identify operative objectives. That does not mean, however, that accessibility is not currently a goal in MTO's decisions – it is in fact implicit in other concerns expressed in Ministry statements and procedures. It is involved in the impacts of transportation services on consumers, business and government. For example, a concern over accessibility is evident in MTO's existing services for handicapped people and in its program of municipal airport development. Thus the question becomes whether an implicit concern in Ministry decisions should be made explicit: should accessibility indicators have a future role in evaluation and communication?

If the Ministry wishes to proceed further with the development and use of accessibility indices, the following steps should be taken.

1) A small project should be funded to prepare a detailed and comprehensive study of how the calculation of accessibility indices can be accomplished. This would include discussions with appropriate Ministry officials who manage data relating to accessibility and the collection of detailed information on the use of data and traffic models at the municipal level. It would also include a preliminary evaluation of specific contexts for which accessibility studies would be useful and feasible at reasonable cost. Such a comprehensive consideration of the scope for accessibility studies was not possible in the present project. The suggested funding level for this preliminary project is $15,000.

2) With the above information in hand, discussions should be held with Ministry personnel to decide which uses of accessibility indices are of highest value. (E.g., should it be for comparing the level of services across population centres; should it be to improve

monitoring in the Municipal Roads subsidy program; should it be to evaluate routes for MTO's own highway construction program?) These decisions will indicate the direction and scope of further efforts.

3) A possible second larger project could then be funded to develop specific methodology and to carry out a pilot project. That is, accessibility indicators would be produced to apply to a decision problem of current interest to the Ministry. The size and cost of this project must, of course, be decided upon when its design details are worked out.

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3/ Indicators of the Impact of the Transportations System Infrastructure on Business Profitability and Competitiveness

3.1/ Introduction

The Ministry of Transportation currently generates indicators of the direct impact of changes in the state of transportation infrastructure (both in terms of capacity and quality) on users. These indicators include changes in travel time, in vehicle operating costs, in safety, and in vehicle maintenance costs. Increasingly the Ministry is being asked to translate these indicators of direct impact into their significance for the economy and society of Ontario. Business, government and consumers are all affected. This proposal addresses one element – the effect of the transportation system infrastructure on business profitability and competitiveness. Other elements will be addressed in subsequent proposals.

The transportation system affects business in several important ways. First, each of the direct impacts is related to business costs, whether business provides its own transportation or purchases transportation services. Second, the reliability of the system – in terms of predictability of travel times – allows saving in other areas of business operations, for example, through the use of "just-in-time" inventory systems.

3.2/ Methodological Issues

A number of alternative approaches to the development of quantitative indicators of the impacts of transportation infrastructure on business have been proposed in the literature (see Diewert [1986], pp. 70-79 for a brief review). Before turning to a discussion of these alternatives, two general observations should be made.

First, the impacts of transportation infrastructure are specific to particular locations. Thus any indicator of these impacts must be defined relative to an impact region, which may be as large as the province of Ontario or as small as a portion of a municipality within Ontario. More than one method of indicator construction may be required, depending on the size of the impact region.

Second, the measured reduction in costs to business resulting from an improvement in the transportation infrastructure is likely to understate the value of the improvement to the Ontario economy. In part, this is because reduced costs to one business may reduce the price of its product

which, in turn, will lead to lower costs for other firms or consumers. Also, cost reductions may lead to new or expanded businesses (induced investment) which will broaden the economic base for the region of impact and lead to further saving. Thus, the set of indicators should attempt to capture these broader impacts. This goal may be approached in two ways. First, a single indicator may be designed which captures all of the impacts (or as many as possible) of the transportation infrastructure improvement. This approach is exemplified by Diewert [1986]. Alternatively, a number of indicators, each corresponding to one aspect of the impacts of the improvement, may be calculated. This latter approach has the advantage of providing a clearer view of the nature of the impacts and the distribution of the benefits across different sectors of the local economy. The set of proposals included here falls into this "package of indicators" approach.

3.3/ Major Research Objectives

3.3.1/ Overview

The major objectives envisioned in this project are outlined below. More detailed discussions of each objective follow this general outline.

1) Identification of the impacts of direct user-benefits (travel time, safety, vehicle operating costs) on the cost of transportation to business.
2) Identification of the relationship between transportation reliability and inventory cost.
3) Identification of the impacts of 1) and 2) on new (induced) investments and on location decisions.
4) Linking reduced business transportation costs to prices of products in Ontario.

3.3.2/ Impacts on Business Transportation Costs

Transportation services are provided both by specialized industries ("for-hire" trucking, courier services, etc.) and by business for itself. Both sources of these services should be investigated in order to determine the overall impact of various transportation system features on transportation costs. Here, reliance should be placed on interviews with a broad sample of suppliers of transportation, supplemented by econometric analysis of relevant cost data. The expertise of the Goods Distribution Office and other sections of the Ministry should also be drawn upon. The emphasis should not only be on measuring actual cost saving but also on determining "willingness-to-pay" for the user-benefits of the transportation system (see Varian [1978], pp. 200-203 for a discussion of questionnaire techniques designed to reveal "willingness to pay").

3.3.3/ Transportation Reliability and Inventory Systems

Generally, transportation may be regarded as an independent activity which does not interact with other business decisions. For example, a reduction in transportation costs may be welcomed by a manufacturer but will not affect his choice of production technique. One exception to this general statement is the management of inventory systems. "Just-in-time" inventory systems, in which raw materials or goods-in-process arrive at the plant and are directly fed onto the production line, are currently used in the Ontario auto industry. These systems depend on the reliability of the transportation system, in particular, on the predictability of transportation times. This reliability may be affected by accidents and congestion, which in turn are related to both system condition and system capacity.

Here the intent is to establish a quantitative link between system reliability and potential inventory cost-saving. (The relationship between conventional measures of system condition and capacity and system reliability is considered in another project). Interviews with businesses which do and those which do not use these inventory systems will be necessary in order to establish the potential base for this type of saving. Input from experts in production management and inventory systems should also be sought.

3.3.4/ Induced Investment and Location Decisions

Other potential interactions between transportation costs and business decisions are the choice of location and the potential for new induced investment. These questions are really two aspects of the same decision. If a business relocates to Ontario or one of its regions, or if a new business locates in Ontario rather than in some other province, then from the perspective of Ontario this is a new induced investment. On the other hand, if the location choice is between two different areas within Ontario, then, from Ontario's perspective, it is a location decision. That is, new investment in Ontario was not induced by the transportation improvement, although the location of that investment may have been influenced. Both aspects of the location decision are of interest to the Ministry, given the emphasis on both general economic expansion and regional development within the province.

The research effort will include gathering information from both the Ministry of Industry, Trade and Technology and municipal economic development offices. This information will be used to:

1) identify types of business whose location choices are most likely to be influenced by the transportation system;

2) identify particular business firms to be interviewed; and

3) identify the aspects of the transportation system which are most relevant to these decisions.

Subsequent efforts would include interviews with affected business, as well as statistical analysis of historical data. These data will be drawn from three sources: the Census of Manufacturers (Manufacturing Industries of Canada: sub-provincial areas, Statistics Canada 31-209); the Census of Canada; and municipal planning departments. The statistical analysis will attempt to link changes in the relevant features of the transportation system to subsequent business investment and location decisions.

3.3.5/ Impacts of Reduced Transportation Costs on Product Prices in Ontario

Because transportation costs are important throughout the Ontario economy, reduction in these costs will have widespread impacts on the prices of products produced within Ontario. One way to measure these impacts would be to calculate the economy-wide price reductions attributable to transportation cost saving, assuming unchanged returns to labour, land, mineral resources and fixed capital investment. This measure would be an indicator of the increased competitiveness of the Ontario economy resulting from transportation improvements.

The price relationships inherent in the input-output system provide a vehicle for calculating this impact, since reduced costs in one industry (transportation) can be traced to reduced costs in others. In this way economy-wide impacts of transportation cost reduction can be calculated. Once the impacts of transportation system characteristics on transportation costs have been established (the first research objective in this proposal), these impacts can be used as inputs into the Ontario input-output data system. Confidentiality limitations on access to the input-output data may require that some calculations be made by the input-output division of Statistics Canada. However, because of the linearity assumptions of the input-output system, these would be "one-time" calculations which need not be repeated until new input-output data became available.

3.4/ Research Plans

The initial phase of this research project should involve the following steps:

1) Preliminary interviews should be conducted with the Ministry's Goods Distribution Office, MITT, several municipal planning departments, and a few selected businesses from both the transportation sector and other industries. These interviews are intended to identify

features of the transportation system relevant to research objectives 1, 2 and 3; sectors of business most affected by these impacts; and other potential information sources.

2) Based on the preliminary interviews, questionnaires relevant to objectives 1, 2, and 3 should be designed.
3) The questionnaires should then be tested on a small sample of relevant businesses and government agencies.
4) The data gathered by questionnaire, together with corresponding statistical data, should then be used in a preliminary evaluation of research objectives 1, 2 and 3.
5) The preliminary measure of cost saving (research objective 1) from (d) can be used as an input into calculating the measure of impact on business competitiveness, using the Ontario input-output system.
6) The questionnaires, other data sources and evaluation methods should be revised, based on the above experience.

Once this initial phase of the research project has been completed, several alternatives are possible. The approach may be applied on a wider scale, both in terms of geographical area and business type. An expanded data base can be developed in conjunction with this broader application. Subsequently the system of impact calculation could be maintained "on-line", with updating performed as needed. Alternatively, the system may be kept "on-the-shelf", to be applied as needed to particular transportation investment projects or programs.

3.5/ Research Effort Estimates

The following estimates are tentative, but should give a general indication of the costs of the initial phase of the project.

Preliminary interviews & questionnaire development	2–3 man-months
Questionnaire testing & data collection	1–2 man-months
Collection of statistical data	1–2 man-months
Data analysis & indicator calculation	1–2 man-months
Calculation of competitiveness indicator	1 man-month
Revision, evaluation & final report	1 man-month
Total estimated cost	**7–11 man-months**

Some data collection efforts associated with other projects may be combined with the above efforts, thereby reducing overall costs.

References

[1] Diewert, Walter E., The Measurement of the Economic Benefits of Infrastructure Services, Springer-Verlag, Berlin, 1986.

[2] Varian, Hal R., Microeconomic Analysis, W. W. Norton, New York, 1978.

4/ Developmental Impacts of Transportation Investments

4.1/ Introduction

Transportation investments often result in changes in the relationship of people and and of business enterprise to commodities and services. Investments affect demands for particular items because time-distance factors adjust and spatial rearrangements occur. Building a highway or other major transportation facility tends to reorganize local economic activity. Development is clustered about it and it is believed that transportation and other industrial costs fall and a more efficient distribution of economic activity over space is produced. Output at given locations is increased and production may be organized into more size-efficient firms. Warehousing, delivery and storage costs can be reduced; industrial parks and shopping centres are developed.

In summary, potential returns to location near a new or improved transportation facility lead to a pattern and level of capital investment that is specific to the nature and routing of the facility. The projects described in this proposal are concerned with the measurement and evaluation of developmental investment that occurs as a result of public sector expenditure on transportation facilities.

It is useful first to set out the various categories of developmental impacts that are claimed to occur as a result of transportation investment. While these claims are by no means mutually exclusive, they should all enter the search for an appropriate analysis at the outset. Following that, various alternative approaches to measuring and analyzing the claimed impacts in a systematic way are outlined. Finally, tentative budgets for the initial development of these methodologies are presented.

4.2/ Developmental Impacts

4.2.1/ Stimulating Private Investment

It is often argued in macroeconomic analysis that public investments do not induce private investments. In fact it is claimed that public investment "crowds out" private investment. In the transportation area there is strong evidence to the contrary. For instance, highways in Canada and the US have triggered large capital expenditure programs, particularly in shopping centres, industrial and research parks and warehousing. See for instance, [1].

4.2.2/ Revitalizing Depressed Areas

Here, the claim is focused specifically on a region. Transportation investments are said to contribute to revitalizing sections of the local economy. It is necessary to assess not only the impacts of the original transportation investment but also the impact of the induced investment that occurs in association with the project. The initial economic base specific to the region in which the investment is undertaken is likely to determine the potential benefits from transportation investment and therefore has to be taken into account in the analysis.

4.2.3/ Rebuilding Central Cities

This measure is very similar to the one above, but often the benefits are defined not only in space but also as they can accrue to a particular social group.

4.2.4/ Strengthening Peripheral Economies

A peripheral economy does not have a diversified industrial base and is dependent on a "centre" that has a diversified economy. Thus this question again focuses on a region but can be very different from cases A and B. It may, for instance, aim at a wider geographical context and be much more focused on the question of economic links with other regions. Strengthening these links may increase the size of the market, reduce the cost of delivery of outputs and receipt of inputs and reduce the spatial separation of workers. The extent of this impact will depend on a number of factors: on the region's existing economic and export base, on how the project would alter and enhance the comparative advantage of the local economy vis-a-vis the provincial economy, on the nature of the investment project and on the extent to which already existing resources would be called upon to meet the requirement of the investment.

4.2.5/ Reducing General Unemployment

An investment in transportation will increase employment and more fully realize the potential of the economy if (a) the local unemployed have skills applicable to the contemplated projects, (b) most of the workers are from inside the region, (c) there are no discriminatory barriers to hiring the unemployed and (d) the work cannot be highly automated.

4.2.6/ Expanding the Local Tax Base

A transportation investment will expand the local tax base in two distinct ways. First, there is the increase in the flow of economic activity during the construction phase. The payment of wages and the purchases of goods and services could provide the local economy with increased tax revenues.

Second, primary and secondary transportation benefits may be capitalized into the land and property values in the local area.

4.2.7/ Redirecting Urban Growth

Urban growth involves substantial costs including the costs of transportation, sewer, water, utilities and other urban services. Thus, transportation investments can help to redirect urban development to specific areas with the aim of reducing these costs.

4.3/ Indicator Construction and Data Requirements

As already noted, the above claims involve considerable overlap. The measurement techniques used to investigate these issues should take into account both the overall developmental effects of transportation investment and also some of the separate impacts mentioned above. Furthermore, it is important to recognize that these techniques must capture both spatial and temporal aspects of the developmental consequences of transportation investment.

Two general approaches to these issues suggest themselves. One alternative is a comprehensive urban systems model that encompasses all aspects of transportation investments. (This approach will be discussed in another proposal). The second approach is based on an input-output analysis. One advantage of this approach is that it can build on the Transportation Impact Model (TRIM) already available to the Ministry. A second advantage is that both regional and dynamic aspects of developmental impacts can be analyzed in the same framework.

This proposal is based on the input-output approach. The temporal aspects of developmental consequences will be dealt with by introducing a specific time element into an input-output structure. The spatial issue will be dealt with in terms of two alternative approaches: a regionalized input-output system and a shift-and-share analysis.

4.3.1/ A Dynamic Input-Output Framework

The economic impacts calculated in a typical static input-output model consist of the initial, indirect and induced expenditures generated by the direct transportation investment. These impacts do not account for any increase in investment that might be triggered by the project involved; rather they are based only on the production required to sustain the project and by extra consumer expenditure due to the increased income it generates. The essence of the problem approached in this proposal is to identify the induced investment effects and capture their impacts.

To do this it is necessary to add to the input-output model a number of investment vectors that represent the expected induced investment over time. These investment vectors may be identified directly by using information based on comparable projects that have been done in the past. (Such an effort is also included in the project concerning transportation investment impacts on business). It may also be accomplished indirectly by relying on capital-output ratios generated specifically to deal with this problem.

If the direct method is used, a data collection process is required. In the normal situation envisioned, the experience in some completed project that is deemed comparable to the contemplated one can be utilized. For example, if the project were to be a by-pass of Toronto, then the most appropriate analogue would be the experience of developments that had taken place around Highway 401. If on the other hand a major highway is contemplated as a corridor between southern Ontario and the north, then perhaps the example of the development around Highway 400 would be most appropriate. Data collection might entail interviewing people in the private and public sector who were involved in the project and in the ensuing development. (This data collection would also be relevant for other projects in the present research program.)

If the detailed commodity composition of these investments is not known, it will be necessary to rely the expansions of capacity that result from the transportation investment. In this case we need to construct two tables of capital coefficients to be added to the static structure of the input-output system used in TRIM: one pertaining to replacement investment and one to net investment. Data on these coefficients are not readily available for all the desired industries. Statistics Canada publishes capital stock series for 20 national industries. These need to be adjusted to reflect the industrial structure of Ontario. Because the provincial input-output data involve more than 20 industries, a new aggregation of the input-output system will be necessary.

The above structure can be represented in terms of the commodity balance equations contained in an input-output model.

$$X_i = \sum_j X_{ij} - \sum_j D_{ij} - \sum_j S_{ij} = Y_i, \qquad i = 1, \ldots n. \tag{1}$$

In this equation, X_i is the total output of industry i; X_{ij} is the total current input requirement by industry j from industry i; D_{ij} represents deliveries for capital replacement required by industry j from industry i to maintain capital stocks at current levels; S_{ij} is the requirement from industry i to support

expansion in the stock of capital goods held by industry j; and Y_i is the delivery to other final demands by industry i. The following relationships are assumed to govern these variables:

$$X_{ij} = a_{ij}X_j \qquad (2)$$

$$D_{ij} = d_{ij}X_j \qquad (3)$$

$$\dot{S}_{ij} = b_{ij}\dot{X}_j \qquad (4)$$

Substituting (2), (3) and (4) into (1), we obtain the dynamic input-output equation:

$$X_i = \sum_j a_{ij}X_j - \sum_j d_{ij}X_j - \sum_j b_{ij}\dot{X}_j = Y_i, \qquad i = 1, \ldots n. \qquad (5)$$

The elements D_{ij} and S_{ij} in equation (1) are not part of the static input-output framework. Together they define gross induced investment. If estimates of the vectors of induced investment associated with a given transportation investment are available, they can be entered as final demands at different periods of time by adding them to the Y_i's on the right-hand side of (1) or (5), replacing the S_{ij}'s. If such information is not available, but new output levels in selected industries expected to locate near the new facility are estimated, these will replace the X_j vector in (5) and the system solved for the new impacts. The difference between the vector of X_i's derived from (1) or (5) and those derived from the static input-output framework provide a measure of the developmental impact of the project considered.

4.3.2/ A Regionalized Framework for Transportation Impact

A regional framework is needed to capture the distribution of impacts over regions. This distribution permits us to address some of the claims made about developmental impacts noted above. In particular, impacts on depressed areas, peripheral economies and directed urban growth can be identified. The construction of such a regional framework calls for the definition of specific regions within the Ontario economy. Various regional breakdowns already exist – the specific choice for this analysis should be made at a later point in the proposed research program. Sufficient data exist in Ontario to allow regionalization at the county level or above.

Data requirements for a regional input-output system are large. However, such models have been applied to studies of the regional impacts of tourism and provincial parks. A similar model could be developed to fit the needs of MTO.

Should the Ministry feel that a regional input-output framework is too expensive, there exists the simple alternative of a shift and share technique. It eliminates some of the data requirements of a full regional input-output system, but it cannot deal with the full range of regional issues that can be handled by the more expensive alternative.

The core of the shift-share technique is the computation of geographical shifts in economic activity based upon data describing the spatial distribution of this activity in two different time periods in response to a past transportation investment. Three components of change are generally distinguished in this analysis:

1) Growth occurring through changes in the national component;
2) Growth related to the specific industrial mix of the regional economy – the regional component;
3) Growth related to spatial advantages of the area – a competitive component.

Using the following notation we define these components in terms of an employment variable:

E_t = aggregate national employment at time t.

E_{ts} = total national employment in sector s at time t.

E_{tis} = employment in region i in sector s at time t.

The following growth rates can be defined. Let r_t = the national aggregate rate of growth in employment over all sectors. Then

$$r_t = (E_t - E_{t-1})/E_{t-1} \quad (6)$$

If r_{ts} = the national growth rate in sector s at time t, then

$$r_{ts} = (E_{ts} - E_{t-1,is})/E_{t-1,s} \quad (7)$$

If r_{tis} = regional growth rate in region i in sector s at time t, then

$$r_{tis} = (E_{tis} - E_{t-1,is})/E_{t-1,is} \quad (8)$$

If the components of growth are labelled as:

NCtis = a national component of growth in region i in sector s at time t;

RC_{tis} = a regional component of growth in region i in sector s at time t;

CC_{tis} = a competitive component of growth in region i in sector s at time t;

and the change in activity level is given as:

$$\Delta E_{tis} = E_{tis} - E_{t-1,is} \tag{9}$$

then,

$$\Delta E_{tis} = NC_{tis} + RC_{tis} + CC_{tis} \tag{10}$$

Further, each component may be obtained from the following equations:

$$NC_{tis} = r_t E_{t-1,is} \tag{11}$$

$$RC_{tis} = (r_{ts} - r_t)E_{t-1,is} \tag{12}$$

$$CC_{tis} = (r_{tis} - r_{ts})E_{t-1,is} \tag{13}$$

Equation (11) implies that the national component of growth for sector s will be the increment if sector s in region i were to follow exactly the national growth when all sectors are combined. When sector s experiences a different growth rate from the national average on account of specific regional industrial mixes, this will be captured by equation (12). Finally, equation (13) captures the locational characteristics of the region which give it specific competitive advantages that yield further growth variations.

Substituting equations 11, 12 and 13 back into (10), we obtain

$$\Delta E_{tis} = [r_t + (r_{ts} - r_t) + (r_{tis} - r_{ts})]E_{t-1,is} \tag{14}$$

To summarize the above, these equations may be used to designate the growth impact of a particular stream of transportation investments on a particular region. They are accounting equations intended to capture national growth impacts, regional growth and shifts in activities between regions as a given investment is undertaken. In use, the framework first involves the analysis of past experience, which then becomes the basis for simulating the effects of a proposed project. In the historical analysis, a national growth rate and a sectoral growth rate are used to determine the residual

component of growth by sector in the region that can be attributed to the project expenditure. In a simulation, the historical national and regional growth rates are assumed to be unaffected by the investment and equation (14) is used to calculate the simulated changes in the regional sectors.

4.3.3/ A Regional Dynamic Input-Output Framework

The dynamic input-output system described above captures the temporal dimensions of the impacts of transportation investments. The regional input-output system captures the spatial distribution of the impacts of transportation investments. A complete picture of these impacts can be obtained by combining the two systems described above.

4.4/ Research Effort Estimates

Since there is more than one alternative, a number of budgets will be presented. The first deals with the input-output framework. A major component of the cost is its substantial data requirements. What is needed are capital-output matrices by industry on the provincial level. Published data on capital by industry exist only at the national level. To construct the table for Ontario would involve substantial effort. In addition, a system of collecting data on the development impacts of past transportation investments is necessary. The effort could easily entail 4–6 man-months.

The development of a regional input-output framework is a complicated procedure that will require substantial investment of both time and resources. The estimated effort of adapting this framework to the needs of the Ministry is 12–14 man-months.

An estimate of the effort of a shift-and-share study is 4–6 man-months.

References

[1] Goldstein, S., "Non-user Benefits from highways". HRR, No. 20, pp. 162–181.

[2] Inal, I.M., "Relationship Between Regional Economic Growth and Transportation Measures", 1981, Mimeo.

5/ The Impacts of Transportation Investments on Land Values

5.1/ Effects from the Physical Environment

5.1.1/ Introduction

When an individual gains title to a piece of property, he is in fact, acquiring a multi-dimensional commodity, the value of which is determined in part by the characteristics of the property and in part by factors external to the property. The land and any structures on it yield a flow of services which contribute to the value of the property. In addition, however, characteristics of the surrounding area, for example, the quality of the environment, local amenities, accessibility to various facilities, zoning, and proximity to other types of land uses, also contribute directly to the selling price of a particular piece of property. According to the Tiebout hypothesis, individuals make their purchase on the basis of the characteristics of the house, property, and surrounding neighborhood. The private valuations of the various neighborhood characteristics are thus capitalized into the values of properties.

It is possible to interpret land values as representing the sum of the valuations of each of the characteristics alluded to above. A subset of these characteristics is influenced in both positive and negative ways by transportation investments. As will be developed in detail below, it is possible, using regression analysis, to estimate the contribution to property value per unit of each characteristic. Using these estimated "shadow prices", it is therefore possible to assess the monetary value of the various impacts of a given transportation investment on contiguous properties.

The development of a comprehensive land valuation model that takes account of all possible impacts of transportation investments is a major undertaking. In this proposal, we deal with a large component of such a model, the valuation of impacts of these investments on the physical environment. Since it has become commonplace in land use decisions to carry out an environmental impact assessment of major projects, the development of an environmental impact indicator is a sensible first step, should MTO decide that a land valuation indicator is desired for purposes of policy-making.

5.1.2/ Assessment of Environment Impacts

Transportation investments of all types alter the physical characteristics of the environment in the vicinity of transportation corridors and facilities in a variety of ways, all of which may be viewed as detrimental to the environment:

1) noise levels increase as traffic volumes increase;

2) air pollutants from vehicle emissions increase;
3) the corridor intrudes visually on the landscape;
4) dirt and debris accumulate;
5) chemical run-off onto adjacent land may occur; and
6) safety levels for persons living along the corridors or adjacent to the facilities may be altered.

The extent to which most, if not all, of these impacts are experienced is correlated with the proximity of the lands and buildings in question to the transportation corridors or facilities.

The damages associated with these environmental impacts serve to reduce the benefits flowing from a given transportation investment. However, if the transportation project under discussion is necessary, then the types of costs being considered here cannot be avoided totally, since presumably the project must be located somewhere. The issue then becomes one of proper planning of the location of these projects, to minimize the adverse effects the project may have on the environment, to the extent possible within the overall set of constraints within which the planning process must operate. A knowledge of the types of impacts that may occur, the distances from the source over which these impacts may be felt, and the resulting damages, may assist the planning process in locating these investments.

The types of damages associated with these physical changes in the environment may be broadly classified as:

1) damage to human health
2) damage to human enjoyment
3) damage to property, and
4) damage to crops and wildlife.

5.1.3/ Methods of Assessment of Damages

Two methods are available to assess the types of damages that may flow from a given transportation investment, the hedonic method and the method hereafter referred to as the 'imputed value method'.

5.1.3.1/ The Hedonic Method

This most frequently used method for assessing environmental damage proceeds by quantification of the physical magnitude (e.g., noise, pollutant level) causing the harm, and the identification of a value indicator, typically the value of properties that are subjected to these environmental effects. The value indicator is then regressed on a set of explanatory characteristics, including the physical measure(s) of environmental damage, that determine the value in question. The estimated regression coefficient of a specified environmental impact variable is a measure of the private sector valuation (or private cost) of the damage caused per unit of the damage source. These estimated regression coefficients, called hedonic prices, give the method its name.

One of the problems with the hedonic method arises from a potential divergence between social and private costs of an environmental contaminant, as may arise in the case of a substance that causes epidemiological damage over a long period of time. To the extent that health effects from this source are not fully perceived by the owners of affected properties, the estimated hedonic or shadow price will understate the true social impact of the source of the damage, because the appropriate risk discount reflecting this hazard will not be built into the market values of the affected properties.

5.1.3.2/ The 'Imputed Value' Method

The second method proceeds by direct quantification of the total damage caused by the specified pollutant. A value is then imputed to this damage, using either direct market valuations (as in the case of crop damage) or imputations of value (for example, the value of a human life, using the methods of human capital theory). The imputed value method is more likely than the hedonic method to arrive at valuations that reflect true social costs associated with the damage source. However, the data requirements appear to be much more extensive.

5.1.3.3/ Comments on the Methods

The suitability of each method depends on the type of environmental damage under consideration. The hedonic method probably captures quite fully the valuation of damage to human enjoyment and to property and crops. However, this method may not capture adequately the damage to human health, wildlife, and non-food types of vegetation. These latter types of damage may be better accounted for by the imputed value method, but both epidemiological and biological data would be required for such a calculation.

This report describes a feasible hypothetical project based on the hedonic method. Indeed, a similar but more narrowly focussed study of the impact of sound barriers on the value of adjacent residential properties, using the hedonic method, was carried out for MTO by Hall and Welland [1].

No attempt has been made to structure a project based on the imputed value method. With existing knowledge, we are unable to provide an informed judgement on the time requirements or costs of a project based on the imputed value method.

The physical impacts on the environment noted previously are likely to be present in varying degrees at specified distances from a given transportation corridor or facility (e.g., an airport). It must be recognized, for a given project, that a number of impacts are likely to be highly correlated with distance from the corridor or facility. For example, in the case of highways, the closer the land is to a given highway with a specified AADT (average annual daily traffic volume), the greater is likely to be the impact of each of the six noted sources of environmental damage. Noise and pollutant levels are likely to be positively associated with proximity to airports. As a result, a study that attempts to measure separately the various environmental impacts of several pollutants may not be possible. In the presence of high correlations among explanatory variables in a sample, one may be forced to let one variable do the work of several highly intercorrelated variables. In such a case, one cautiously interprets the resulting coefficient as the net damage cost across all correlated measures per unit of the retained variable. This constraint, known as the multicollinearity problem, is almost certain to be encountered, indeed is quite unavoidable, in a study of the type proposed below. In spite of this limitation, it may be possible to obtain a reasonable assessment of the private costs of environmental damage caused by transportation projects in the proposed study.

5.1.4/ Design of the Study

The hedonic method involves the estimation of regression equations in which the dependent variable is a measure of the value of the property (for example, a recent sale price), and the explanatory variables consist of various characteristics of the property thought to affect the property value. Included in the set of explanatory variable is the set of environmental measures discussed previously. For each type of transportation facility considered, a sample must be obtained of properties at different distances from the transportation project. For each property in the sample, information must be collected on the relevant property characteristics and the quantities of the environmental pollutants reaching the site.

One location in which the required data are available is the city of Toronto. All manner of transportation modes and facility types exist within the city limits and the Toronto Real Estate Board has proven to be a rich and cooperative source of data on property prices and housing characteristics. Using Toronto as the basis for illustrating the method, a sample of homes that have traded in a recent time interval, perhaps five or ten years, that stand at different distances from the facilities and corridors selected, can be gathered from the Toronto Real Estate Board files. From these listings, a set of relevant housing characteristics for each property can be extracted. The set of characteristics should include the following measures:

1) type of dwelling
2) binary variables indicating the presence of such things as
   a) a garage
   b) a swimming pool
   c) central air conditioning
   d) a paved driveway
   e) a finished basement
   f) noise barrier
3) number of rooms
4) number of bathrooms
5) number of apartments
6) lot size
7) number of appliances
8) recent selling price
9) property taxes

Predicted noise levels at each site can be generated using Ministry resources. The noise prediction model Stamina 2.0 is adequate for this purpose.

A gas diffusion model may be used to predict the volumes of air pollutants present at different distances from the emission source. For example, a model due to Hickman and Colwill [2] can be used to predict carbon monoxide concentrations at various points in a gas cloud caused by motor vehicle traffic on the basis of values for traffic flow, traffic speed, road layout, and wind speed and direction. Information on all of these variables, with the possible exception of wind speed and direction (which variables may be available as daily or seasonal averages from Environment Canada),

can be obtained either from the Ministry's own records, or from actual measurements taken by Ministry personnel in accordance with the needs of the study.

The model of Hickman and Colwill contains equations that permit the extraction of measurements of other pollutants, (e.g., hydrocarbons, oxides of nitrogen and oxides of lead), directly from the carbon monoxide measurement. Since each measured pollutant level other than carbon monoxide is an exact linear function of the carbon monoxide level, only one pollutant measure, presumably but not necessarily the carbon monoxide measure, should be used in the hedonic regression, in order to avoid the problem once again of multicollinearity in the regressor set.

Data permitting, it is desirable to estimate shadow prices for as many separate environmental variables as possible. However, it may be possible to use only one environmental variable to capture the effects of all environmental variables, if they all turn out to be highly intercorrelated. In such a case, the coefficient of the included variable is interpreted as the net effect of all of the environmental variables per unit of the variable included as a regressor.

A set of binary variables, for type of transportation mode, and possibly for the type of facility within a given mode, may be used to detect the combined effects on property values of dirt and debris, chemical runoff and safety, each of which may be difficult to quantify separately. Alternatively, a binary variable reflecting a property bordering a transportation corridor or facility may be sufficient to capture the combined effects of these factors on the property value. Interactions of the modality binaries with the noise and air pollution variables may also be considered in order to account for intermodal differences in the impact of these characteristics.

Once these data have been collected, both for sites close to and at a distance from the source of the damage, including homes beyond the range of the impact, a set of regression equations can be run to estimate the shadow prices of the various environmental impact variables. It may be desirable to work with equations specific to a given mode, and also to investigate equations based on the pooling of data from several modes.

Having obtained the shadow prices of the pollutants, either separately or as the net effect of several influences, total environmental damage along a standard unit length of a given corridor (say, for example, a one kilometer stretch of four-lane divided highway) in a given setting (urban or rural) can be approximated. The limits of the environmental impacts (i.e., the distance at which ambient noise

and pollution levels have been reduced to normal background levels) of a given project can be detected with the gas diffusion and Stamina models. These limits can be used to determine the number of homes and the total environmental damage at each site in the standard interval. Total damage at each property is found by multiplying the estimated regression coefficient (or coefficients) by the value(s) of the environmental variables reaching the site. Total damage along the standard unit interval is simply the sum of the measured damages at each site within the identified limits of environmental impact.

5.2/ Sample Research Effort Estimates

5.2.1/ Sample Estimates

An estimate for this project, based on investigation of four corridors or facilities using Toronto Real Estate Board data, with 500 observations at each site, is projected as follows:

1) Research Assistants
   Data Collection (2000 observations in 4 locations)
   a) From Toronto Real Estate Board: 25 days
   b) From Ministry: 10 days
   Data Entry and Calculations 25 days

2) Computer Cost $2000

3) Travel and Supplies $4000

4) Faculty Supervision 30 days

5) Overhead at 45%

5.2.2/ Extensions

If it were decided to carry out a comparable study in a less-developed area, for example in Central or Northern Ontario, costs would rise since funds would be required for extended travel and accommodation in order to collect the necessary data for the study. Even if it is not possible to obtain the requisite data on residential properties from the relevant local real estate board, it may be possible to use data on building lot transactions to assess the environmental impacts of transportation investments in these areas.

It might also be desirable to expand the hedonic model to include other measures of impact, for example, accessibility, developmental and travel time indicators. The major data requirements for such an effort are no different than those required for the individual project descriptions described throughout this report. It would be necessary only to assess these accessibility measures, travel time measures, and developmental impact measures for the same properties for which the environmental influences were measured. If this more global type of approach to the measurement of the impacts of transportation investments is deemed desirable by the Ministry, coordination across projects designed to measure various impacts will be necessary.

Assuming that the data on these various additional impact measures are already available, having been generated in separate projects, the extra work involved in carrying out this broader project would require perhaps a 4–6 man-month effort.

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6/ Assessing and Evaluating Impacts of Transportation Investments on Land Use

6.1/ General Overview

Attempts to evaluate land use impacts can be divided into two types: ex post (retrospective) and ex ante (prospective) [Goldberg, 1984]. Ex post studies examine the impacts of past projects while ex ante studies attempt to predict impacts of future projects. The most common approaches used in ex post studies are the case study approach (see, for example, Ayer and Hocking, 1986) and the econometric approach (see, for example, Buffington, Chiu and Memmott, 1985). The econometric approach can also be applied to ex ante studies. A second approach to ex ante studies is the "urban system model" (see Anas, 1980 for an example). These approaches differ both in terms of the nature of the results and the requirements for data.

The objectives of MTO are primarily related to evaluating the impacts of new transportation projects – the ex ante problem. However, there may also be interest in examining the impact of past projects – the ex post problem. Thus, any methodology should be applicable to both questions. The case study approach is more appropriate to evaluating past projects since results aredifficult to extrapolate to new and different situations.

The case study approach also leads to qualitative results, whereas our emphasis is on developing quantitative measures of impact. Both the econometric approach and the urban system model give quantitative results.

A final consideration is the degree to which the method both predicts impacts on land uses and attaches economic values to these uses. The econometric approach can predict changes in quantitative measures of land uses, but a separate evaluation of these changes (which could also be based on econometric methods) must be made. On the other hand, the urban systems model may provide quantitative predictions of changes in both land uses and land values. In addition, depending on the structure of the urban systems model, it may provide utility based measures of value such as consumer surplus.

The econometric and urban systems model approaches are described in more detail below.

6.2/ The Econometric Approach

In this approach, data on past projects is used to explain changes in land use patterns in a system of econometric equations. Typically land uses are measured by the fraction of land in a particular affected area (these may be subdivided according to distance from the project) used for each purpose. These uses are then explained by the presence or absence of the project, particular features of the project, and other relevant variables not associated with the project, such as proximity to population centres. A proper specification should also explain other impacts of the project, such as traffic flow, which may affect land use. Thus, a simultaneous equation system which explains all impacts of the project should be extimated. A simple hypothetical example is given below.

$$PRES_{it} = a_{10} + a_{12}PNRES_{it} + a_{13}TRAF_{it} + b_{11}POP_{it} + c_{11}PROJ_t$$

$$TRAF_{it} + a_{20} + a_{21}PRES_{it} + a_{22}PNRES_{it} + b_{21}POP_{it} + c_{21}PROJ_t$$

$$PRES_{it} + PNRES_{it} = 100$$

where

$PRES_{it}$ and $PNRES_{it}$ are percentages of land in area i in residential and non-residential use in period t

$TRAF_{it}$ is traffic flow in area i in period t

POP_{it} is a population characteristic relevant to area i in period t

and $PROJ_{it}$ is a characteristic of the project in area i in period t

Once such a model is estimated it can be used for ex post (counterfactual) simulations to see the impact of more or less or no project on land use as well as for ex ante simulations of the impact of new projects. Note that the problem of valuing changes in land use is not addressed by the model and must be carried out in a second step (see Falcke, 1982).

Estimation of such models requires detailed data on small areas, which may be publically available only from census data at five or ten year intervals or may require special data from local planning offices. In order to apply such a model to a wide range or areas, the data base should not be too specific to a particular area, but instead drawn from a wide range of areas. This, however, requires a larger data base. There are ample opportunities to test such a model on projects not included in the data set. These tests would then provide a basis for revision and improvements. It is likely that

models would perform best if they were tailor-made to specific project types (such as highways, rapid transit, etc.) so that a family of such models (or modules) may be invisaged.

The useful output of such models is to quantify the impact of transportation projects on land use and development.

6.3/ Urban Systems Models

Urban system models differ from the econometric approach in the nature of their output. In particular, these models not only predict changes in physical land uses, but also the accompanying changes in land values (or land-rents). In fact, these models may also have components which are based on econometric techniques.

A second way in which urban systems models differ from econometric models is that they tend to be "tailor-made" to specific urban systems. For example, an urban systems model could be constructed for Toronto and the surrounding areas along the shore to Hamilton and along the 401 to Milton or Guelph, along the 400 and along the 401 east of Toronto. This model could then be applied to the impact of any transportation project within this region.

The above observation highlights a third way in which urban systems models tend to differ from the econometric approach. Urban systems models typically encompass a variety of transportation modes in a single model, whereas econometric models tend to be applied to individual modes. In principle, however, there is no reason why the econometric approach could not be the basis for a single comprehensive model. There may also be some merit to a compromise between these two extremes in which modules appropriate to different transportation modes have interfaces which allow them to be used together in either a recursive or a simultaneous structure.

Within the class of urban systems models there are two fundamentally different modelling styles of types. These may be described by key words such as "engineering" or "empirical" on the one hand as opposed to "economics-based" or "theoretical" on the other. (These terms are not intended to be pejorative, but rather to give some feeling for the differences in these two modelling styles). The first approach tends to be built around distributions which may describe the distribution of land rents, land values, population and land uses. Functional forms (types of distribution) are chosen on a priority ground and then parameter values are selected to conform to particular data sets (usually cross-section). These distributions are linked to the presence of transportation facilities. This style of

urban systems model is described in Wilson (1974) and examples are found in Wilson, Rees, and Leigh (1977).

The second style of urban system modelling is illustrated by the model of Anas (1980). Here the model is based on economic-psychological discrete choice theory as applied to transportation mode choice, extended to encompass choice of residential location and housing type. This component of the model generates household demands for housing by type and location and for transportation by mode. Demands for commercial and industrial land (agricultural uses tend to be treated residually) must also be generated. Demands for land are then confronted with supplies in supply-demand balances. Land rents are adjusted (these affect demand) until supplies equal demands. In this way the pattern of land rents is generated at the same time as the pattern of land usage. Land rents can then be capitalized to yield land values. Since the household demands are utility based (from the discrete choice theory), measures of improvement in household welfare can be calculated from the results. Transportation projects can impact the model in two ways. First, an entirely new mode of transportation, such as a rapid transit system, can be introduced. Second, changes in travel times or other implications of system improvements to existing modes can be introduced into the household demand functions.

Data requirements for urban systems models are very substantial. Because of their broad scope, a wide variety of data at a detailed locational level is necessary. Again, census data and local planning data are the basic sources. The broad scope of these models also implies that development costs are very large.

6.4/ Summary

Two approaches to measuring the impacts of transportation investments on land use are available; the econometric approach and the urban systems model approach. The econometric approach lends itself to relatively small modules, each corresponding to a particular transportation mode. These modules could be designed so that they could be linked together for complex applications. They could also be broadly based so that the same module could be applied to investments in different geographic areas. Because the econometric approach leads to measures of land use but not to changes in land values, changes in land values must be calculated in a separate module.

The urban systems model is a comprehensive model which encompasses all transportation modes and land uses. Thus it does not allow a modular structure. It can be "tailor-made" to a particular urban area, but must be modified for application to different areas. The urban systems model

generates changes in land values as a part of its output and also allows calculation of welfare improvements based on household utilities.

While both approaches have extensive data requirements, the urban systems model requires more data. In addition, because of its comprehensive nature, the urban systems model would require both longer development time and larger development cost.

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